Chemical Process Instrumentation

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Lecture – 37
Temperature Measurement (Contd.)

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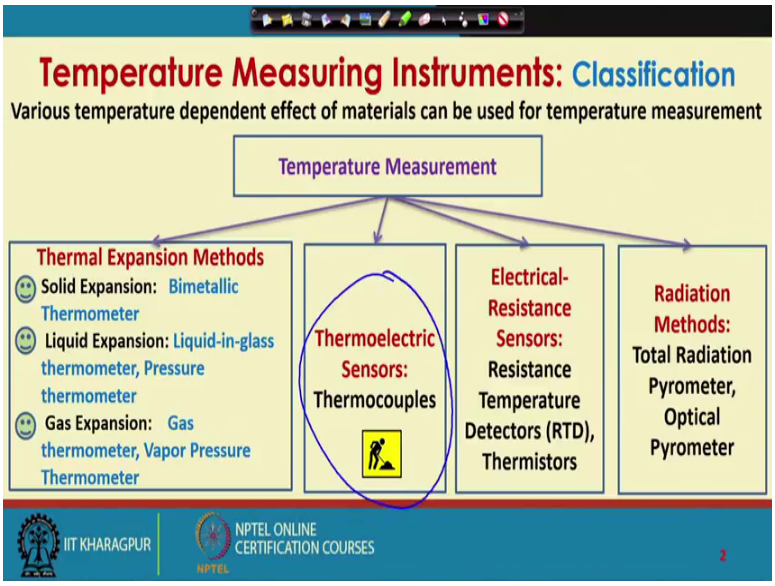

Welcome to lecture 37. In our previous lecture, we started our discussion on thermocouples. So, in this lecture, we will continue our discussion on thermocouples. So, we will continue our discussion on thermocouples which is a thermoelectric sensors.

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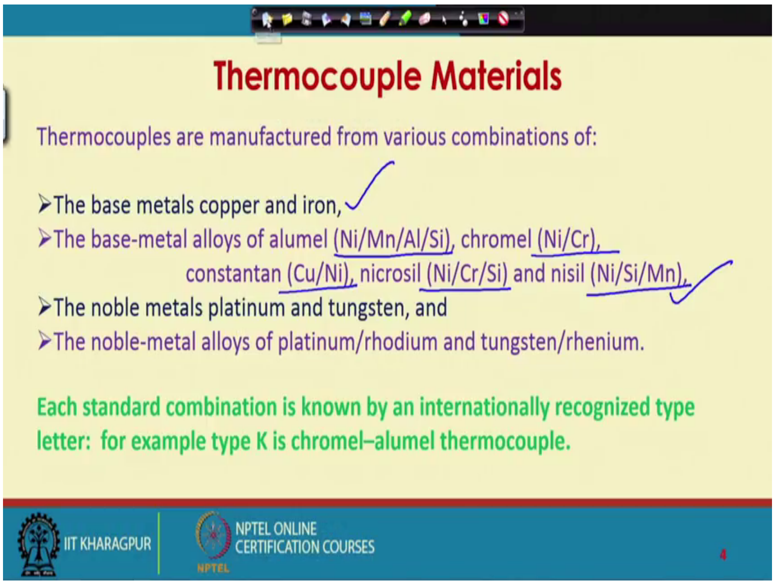

So, now let us talk about thermocouple materials. As of now we have seen what a thermocouple is how to make thermocouple junctions, what are the different junctions, what is Seebeck effect, Peltier effect, Thompson effect, and what are the different thermocouple laws. We have seen all these things in our previous lecture. Now, let us talk about thermocouple materials and different types of thermocouples that are available for measurement of temperature in laboratory or in industries.

Thermocouples are manufactured from various combinations of base metals copper and iron. The base metal alloys of alumel, chromel, constantan, nicrosil and nisil, these are all alloys. Alumel is alloy of nickel, manganese, aluminium and silicon. Chromel is alloy of nickel and chromium. Constantan is alloy of copper and nickel. Nicrosil is alloy of nickel, chromium and silicon. And nisil is alloy of nickel, silicon and manganese. The noble-metals platinum and tungsten, and the noble-metal alloys of platinum rhodium and tungsten rhenium. So, these are the different materials which are commonly used for manufacture of thermocouples. So, we use these metals in various combinations to make different types of thermocouples.

Each standard combination is known by an internationally recognized type letter; for example, type K is chromel-alumel thermocouple. So, in industry the thermocouples are known as a letter, it is represented by a letter like say type E, type K, type J, type N and so on and so forth. We will take a look at the list now type K is chromel-alumel thermocouple. So, instead of saying chromel-alumel thermocouple, in industry we call it type K thermocouple. And this is internationally recognized. So, everywhere type K thermocouple indicates a thermocouple which is made of a combination of chromel and alumel.

There is also another point in it; like, it always takes two dissimilar metals to form a thermocouple. So, we call one positive another negative. We always use first one to indicate the positive metal, and the next we indicate the negative metal. For example, when I say that type K thermocouple is basically a chromel-alumel thermocouple, the chromel is the positive metal and alumel is the negative metal. This is also well accepted and internationally recognized.

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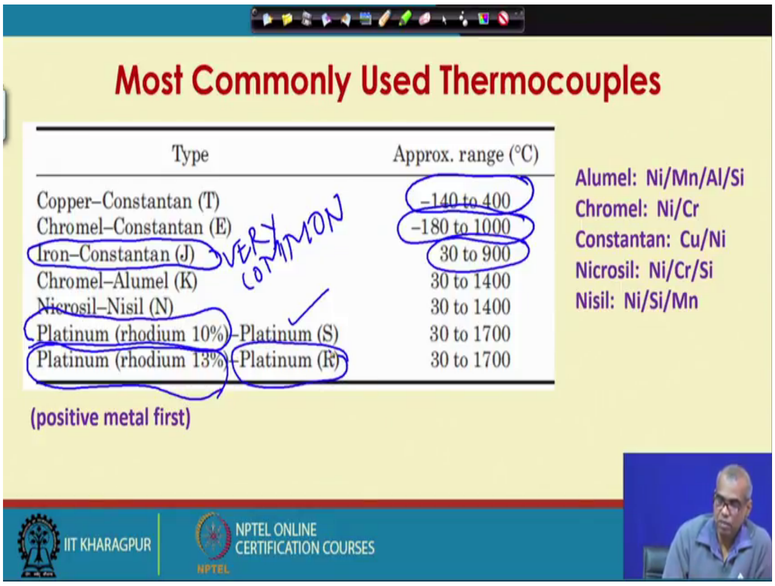

So, we have list of some of these different types of thermocouples approximate ranges in degree Celsius unit is also indicated. So, copper constantan thermocouple is known as type T thermocouple. We will always indicate the positive metal first. So, copper constantan thermocouple, we have copper as positive metal, constantan as negative metal. Copper constantan thermocouple can be used in the range of minus 140 degree Celsius to 400 degree Celsius. Similarly, chromel-constantan thermocouple which is known as type E can be used in the range of minus 180 to 1000 degree Celsius

Iron-constantan can be used for 30 to 900 degree Celsius and this is represented by letter J. So, type J is iron constantan thermocouple it is one of the most commonly used thermocouple in chemical process industry. So, this is very common. Most widely used one of the most widely used thermocouple in the range of 30 to 90 degree Celsius is type J or iron-constantan thermocouple.

Similarly, chromel-alumel - type K, nicrosil-nisil - type N. Platinum rhodium platinum thermocouples can be used for measurement of high temperatures as high as 1500 degree Celsius to 1700 degree Celsius. So, platinum rhodium 10 percent is one metal platinum is another metal. So, this combination can be used in the approximate range of 30 to 1700 degree Celsius. Similarly, platinum and rhodium-13 percent, and platinum can be used in the same range of 30 to 1700 degree Celsius. So, what it basically means is that here the positive metal consists of 90 percent platinum and 10 percent rhodium; and the negative metal consists of 100 percent platinum. So, this is type S. The next is the positive metal consists of 87 percent platinum and 13 percent rhodium and the negative metal consists of 100 percent platinum. So, this is type R.

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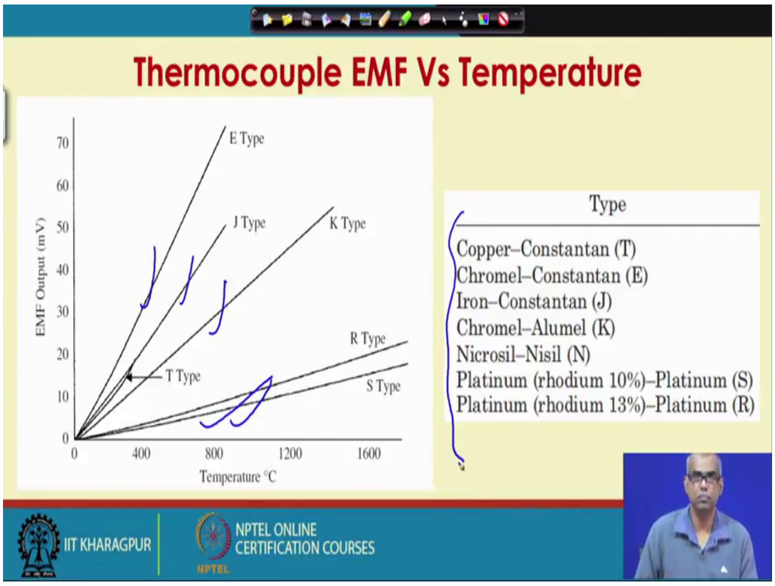

This is a schematic of how the EMF output in millivolt varies with temperatures for different types of thermocouples. You can see in the figure that most of them are approximately linear, not all are linear, but they are approximately linear. So, this is a schematic representation of variation of EMF output in millivolt with respect to temperature expressed in degree Celsius for different types of thermocouples.

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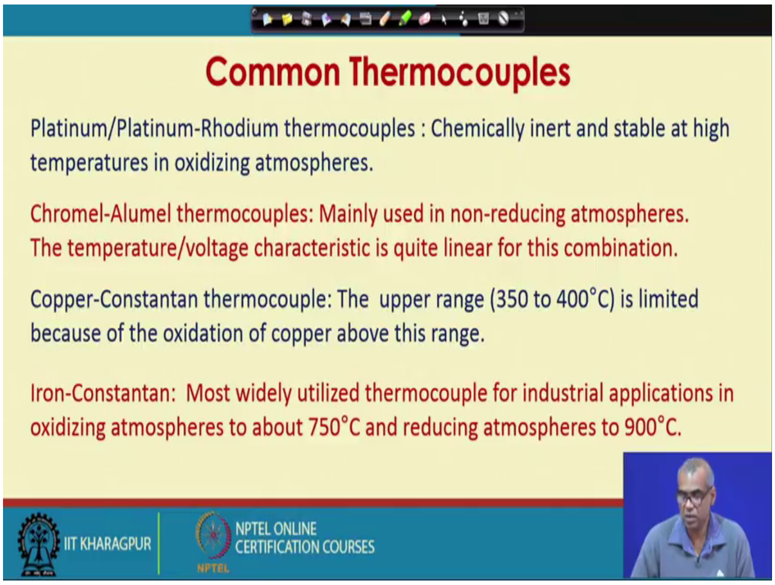

Now, let us talk about certain points about the common thermocouples. Platinum platinum-rhodium thermocouples one interesting feature about this thermocouple is they are chemically inert and they are also stable at high temperatures in oxidising atmosphere and that is why it can be used in temperatures as high as 1500 degree Celsius or 1700 degree Celsius. Chromel-alumel thermocouples, they are mainly used in non-reducing atmospheres. The temperature voltage characteristic is quite linear for this combination. Copper-constantan thermocouples, the upper range which is 350 degree Celsius to 400 degree Celsius is limited because of the oxidation of copper above this range. So, oxidation of copper may take place beyond 400 degree Celsius, and this limits the upper range for copper-constantan thermocouples. Iron-constantan thermocouple, this is most widely utilized thermocouple for industrial applications in oxidizing atmospheres to about 750 degree Celsius and reducing atmospheres to 900 degree Celsius.

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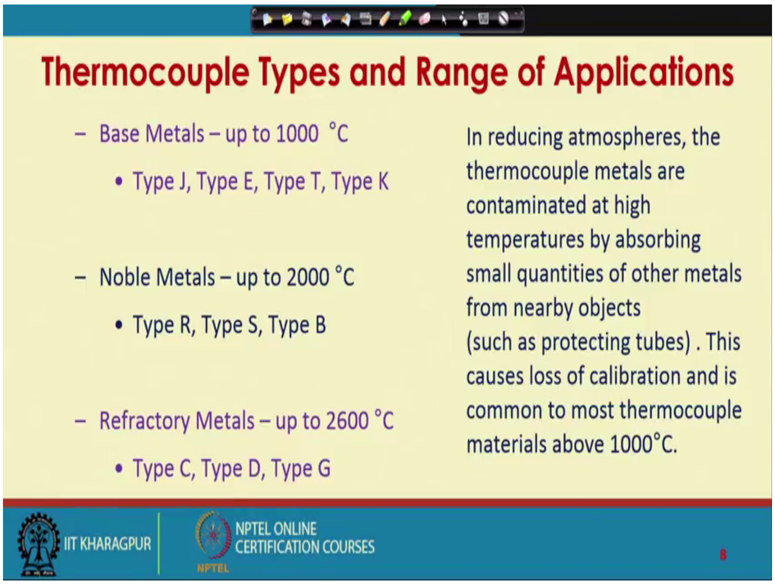

This is another summary of different types of thermocouples and their range of applications. Thermocouples made up of base metals they are generally used to measure temperatures up to 1000 degree Celsius, examples are type J, type E, type T, type K. Thermocouples made up of noble-metals they can be used up to 2000 degree Celsius or 1700 degree Celsius these are all indicative ranges. So, if you look at different differences there may be a difference of say 100 degree Celsius or something like that at the higher range. So, they are thermocouples made up of noble metals type R, type S, type B.

Thermocouples made up of refractory metals they can be used for measurement of even higher temperature up to 2500 to 2600 degree Celsius; type C, type D, type G. In reducing atmospheres, the thermocouple metals are contaminated at higher temperatures by absorbing small quantities of other metals from nearby objects such as protecting tube this causes loss of calibration and is common to most thermocouple materials above 1000 degree Celsius

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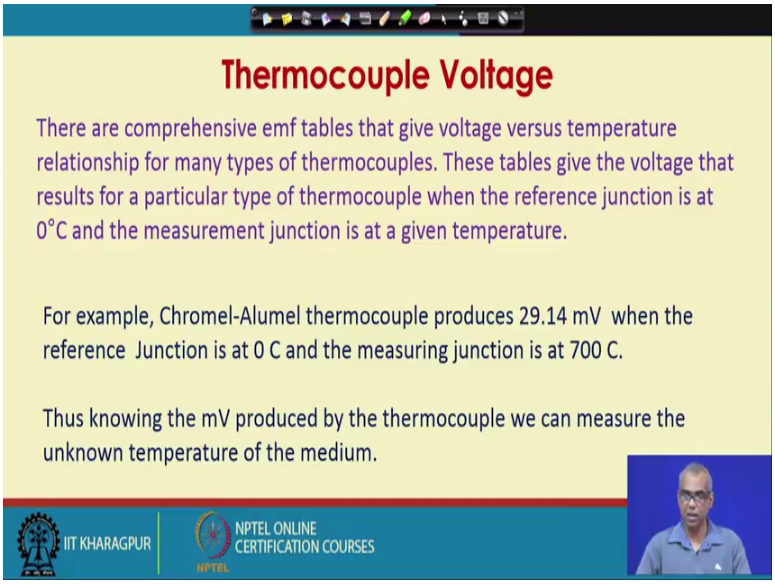

Thermocouple voltage, now the thermocouple always produces voltage in the range of millivolts and that millivolt corresponds to the temperature difference for a given thermocouple that exists between the hot junction and the cold junction. So, I have to know that if thermocouple produces a particular millivolt, what that millivolt corresponds to in terms of temperature. So, it corresponds to a temperature difference. So, now we have said that for making a thermocouple an useful temperature measuring instrument, one junction must be kept at constant temperature.

So, there are comprehensive tables you will see at in different books where the EMF produced by given thermocouples will be indicated, if the reference junction is kept at 0 degree Celsius and the measuring junction temperature is at any given temperature. So, this table is useful source of information, so that we can calculate the temperature of the medium whose temperature I am measuring when I know the millivolt produced by the thermocouple. So, there are comprehensive emf tables that give voltage versus temperature relationship for many types of thermocouples these tables give the voltage that results for a particular type of thermocouple when the reference junction is at 0 degree Celsius and the measurement junction is at a given temperature.

For example, chromel-alumel thermocouple produces 29.14 millivolt when the reference junction is at 0 degree Celsius and the measuring junction is at 700 degree Celsius. Thus knowing the millivolt produced by the thermocouple, we can measure the unknown temperature of the medium. So, for an application with chromel alumel thermocouple if the thermocouple produces 29.14 millivolt and the cold junction is kept at 0 degree Celsius, then we know that the measuring junction is at 700 degree Celsius, but it may not always be possible to keep the reference junction or cold junction at 0 degree Celsius. So, correction will be required, and we will talk about that.

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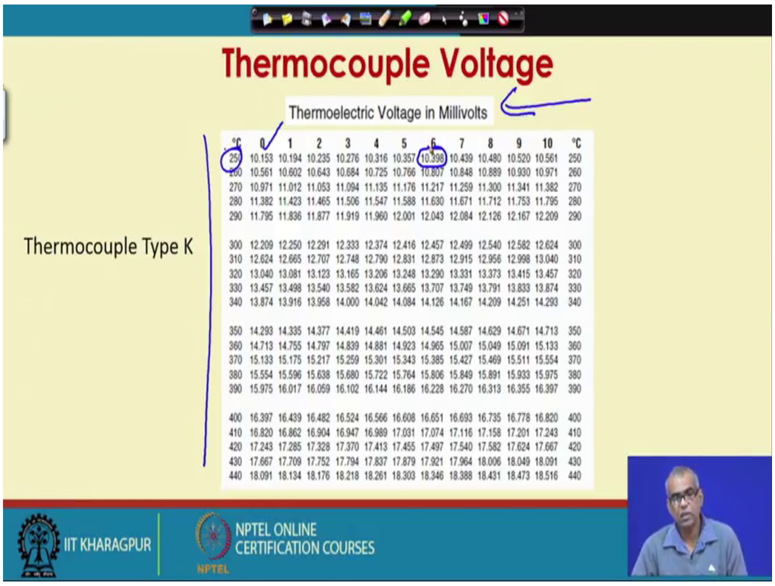

°C	0	1	2	3	4	5	6	7	8	9	10	°C
250	10.153	10.194	10.235	10.276	10.316	10.357	10.398	10.439	10.480	10.520	10.561	250
260	10.561	10.602	10.643	10.684	10.725	10.766	10.807	10.848	10.889	10.930	10.971	260
270	10.971	11.012	11.053	11.094	11.135	11.176	11.217	11.259	11.300	11.341	11.382	270
280	11.382	11.423	11.465	11.506	11.547	11.588	11.630	11.671	11.712	11.753	11.795	280
290	11.795	11.836	11.877	11.919	11.960	12.001	12.043	12.084	12.126	12.167	12.209	290
300	12.209	12.250	12.291	12.333	12.374	12.416	12.457	12.499	12.540	12.582	12.624	300
310	12.624	12.665	12.707	12.748	12.790	12.831	12.873	12.915	12.956	12.998	13.040	310
320	13.040	13.081	13.123	13.165	13.206	13.248	13.290	13.331	13.373	13.415	13.457	320
330	13.457	13.498	13.540	13.582	13.624	13.665	13.707	13.749	13.791	13.833	13.874	330
340	13.874	13.916	13.958	14.000	14.042	14.084	14.126	14.167	14.209	14.251	14.293	340
350	14.293	14.335	14.377	14.419	14.461	14.503	14.545	14.587	14.629	14.671	14.713	350
360	14.713	14.755	14.797	14.839	14.881	14.923	14.965	15.007	15.049	15.091	15.133	360
370	15.133	15.175	15.217	15.259	15.301	15.343	15.385	15.427	15.469	15.511	15.554	370
380	15.554	15.596	15.638	15.680	15.722	15.764	15.806	15.849	15.891	15.933	15.975	380
390	15.975	16.017	16.059	16.102	16.144	16.186	16.228	16.270	16.313	16.355	16.397	390
400	16.397	16.439	16.482	16.524	16.566	16.608	16.651	16.693	16.735	16.778	16.820	400
410	16.820	16.862	16.904	16.947	16.989	17.031	17.074	17.116	17.158	17.201	17.243	410
420	17.243	17.285	17.328	17.370	17.413	17.455	17.497	17.540	17.582	17.624	17.667	420
430	17.667	17.709	17.752	17.794	17.837	17.879	17.921	17.964	18.006	18.049	18.091	430
440	18.091	18.134	18.176	18.218	18.261	18.303	18.346	18.388	18.431	18.473	18.516	440

So, this is how this thermocouple EMF table looks like. This thermoelectric voltage is given in millivolts and only a portion has been indicated. So, these information are available in standard references in many books for various types of thermocouples and at various temperatures. So, how you read it, 250 degree Celsius, you have this is the EMF if the measuring junction is at 250 degree Celsius, and the reference junction is at 0 degree Celsius. So, this is the EMF produced when the measuring junction is 256 degree Celsius and the reference junction is 0 degree Celsius and so on and so forth you can read the thermoelectric voltage from this table easily.

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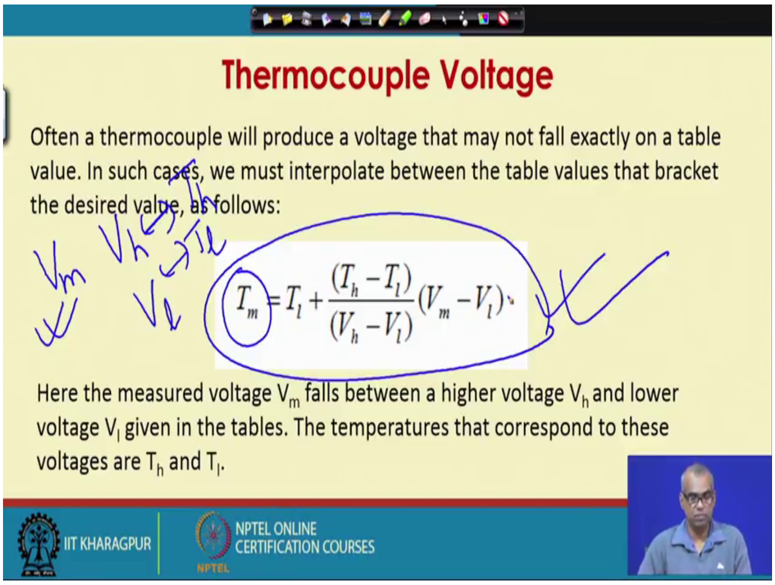

Now, as you see here, the table gives you what will be the EMF produced if the measuring junction is kept at certain temperature, and the reference junction is always kept at 0 degree Celsius. Now, during your actual application, the output of the thermocouple will be a millivolt. And you need to know what is the temperature of the medium or what is the temperature at the measuring junction. So, you have to look at the voltage here and then the corresponding temperature you will be able to find out

Now, it may be the case in fact often it will be the case, the thermocouple will produce a voltage that may not fall exactly on the table value; in such cases we must interpolate between the table values that bracket the desired value. And this formula can be used for interpolation. Suppose, my thermocouple gives me an output which is V m millivolt. Now, I see the table and find out that there is no such value listed, but there is a value which is slightly higher than V m let me call that as V h. And there is also a value which is slightly lower than V m let me call that V l. So, V m is bracketed between V h and V l corresponding to V h, I find that T h is the temperature of the measuring junction from the table. Similarly, V l corresponds to measuring junction temperature T l. Then I make use of this formula for interpolation. So, measuring junction temperature corresponding to output voltage V m is T l plus T h minus T l by V h minus V l into V m minus V l. So, this is a simple interpolation formula.

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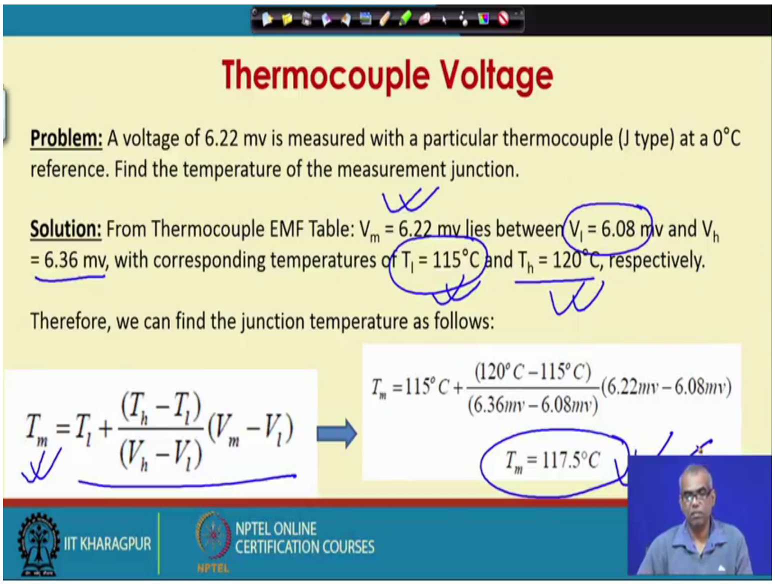

So, let us clarify it further by taking help of a simple example. A voltage of 6.22 millivolt is measured with a particular thermocouple J type at 0 degree Celsius reference. Find the temperature of the measurement junction. So, voltage of 6.22 millivolt is measured with a particular thermocouple J type, reference junction is at 0 degree Celsius. Find the temperature of the measurement junction. From the thermocouple EMF table, we see that V m equal to 6.22 millivolt lies between V l equal to 6.08 millivolt and V h equal to 6.36 millivolt. I do not find any temperature corresponding to V m equal to 6.22, this 6.22 is not listed in the table let us say, but I see that there is 6.08, there is 6.36, and I have a value in between.

So, corresponding T h and T l are 120 and 115. So, once I know V h and the corresponding T h, I know V l and the corresponding T l, I can find out T m corresponding to V m using the interpolation formula. And I find that the junction measuring junction temperature is 117.5 degree Celsius. Note that this has to be in between T h and T l and that is also the case.

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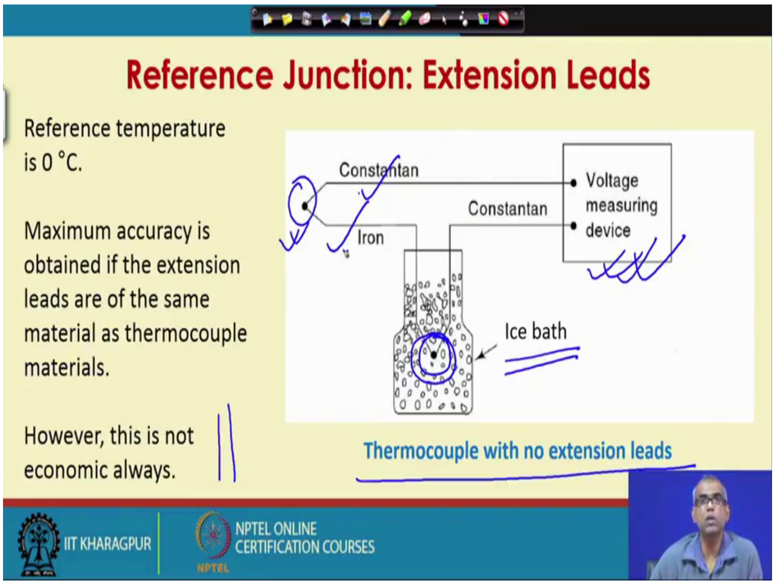

So, as we are talking about the reference junction is 0 degree Celsius for those thermocouple EMF tables. So, in the figure, we have an iron-constantan thermocouple. Measuring junction is indicated here, and the cold junction or reference junction is here. See this thermocouple this schematic shows the thermocouple with no extension lead. So, maximum accuracy is obtained, if the extension leads are of the same material as thermocouple materials. So, you just keep the junction at 0 degree Celsius using ice bath. The millivolt produced will be taken as a measure of the junction temperature.

Here we have not used any extension lead, any extension lead made of metals other than constantan and iron, but this is not economic always. Suppose, we are using platinum rhodium-platinum thermocouple, and this voltmeter may be located at some distance from the point of measurement. So, it is not economical to use a very long wire made of the same metals as the thermocouple metals, because it will be unreasonably expensive and that is not need also.

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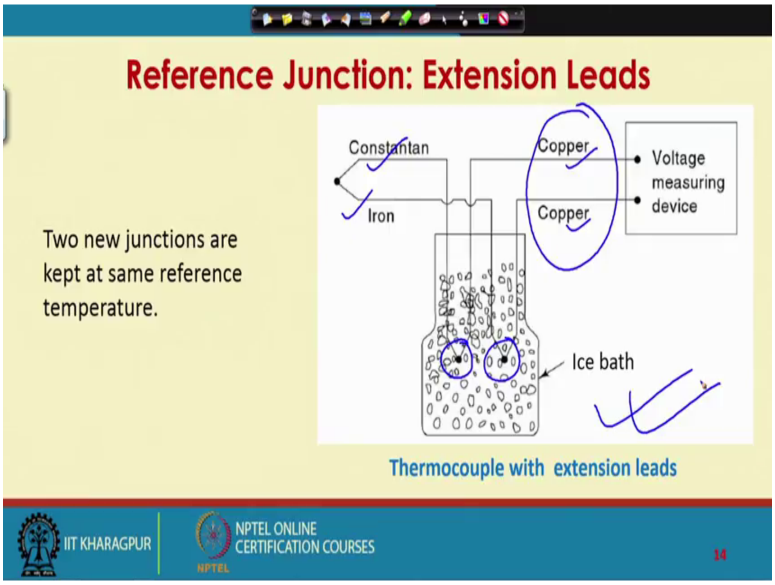

So, we basically will use extension leads made from different materials. Here the thermocouple is made of iron and constantan, but I have used copper as extension leads. See the two extension leads that are coming from the voltage measuring device is joined with constantan and with iron. See, of course, maximum accuracy is possible when you will have constantan iron everywhere. So, if there is no extension lead made of copper, so the constantan goes straight to the voltage measuring device, iron goes straight to the voltage measuring devices and there is a single junction here, but as we discussed that will not be uneconomic that will be uneconomic will not be economic at all. So, we will make use of extension leads which are made of different metals.

Ideally, we should use materials for making extension leads, which has similar thermoelectric behaviour as the thermocouple materials. Now, when we use say copper as extension leads for iron-constantan thermocouple, so I create two new junctions. Now, these two new junctions are kept at the same reference temperature 0 degree Celsius as shown in the figure. So, this will give you fairly accurate result for the temperature measurement.

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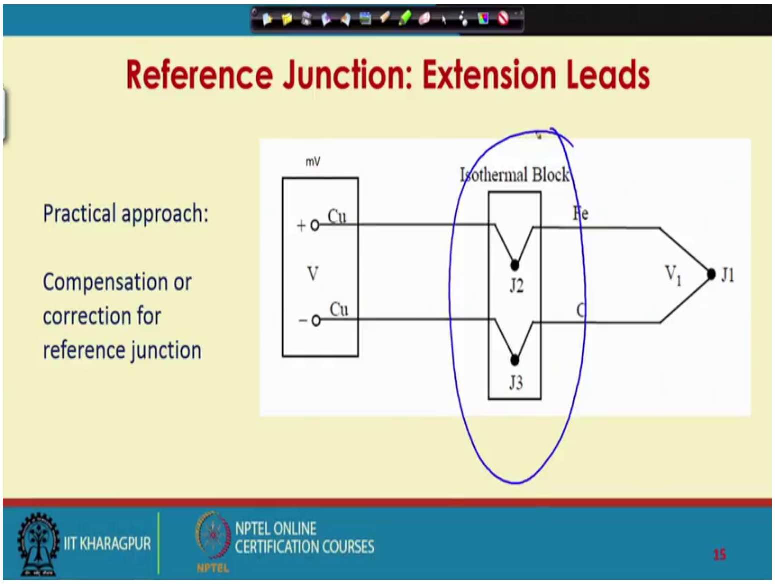

Now, keeping the junction temperature at 0 degree Celsius may not be always practical. So, keeping the reference junction temperature always at 0 degree Celsius may not be practical. So, our practical approach will be keep this two junctions at some constant temperature, and known temperature, and then make compensation or corrections for the changes in the reference junction, so that is a practical approach. That instead of keeping these two new junctions at 0 degree Celsius, I keep it at a temperature which I can measure accurately, but both the two junctions are kept at same temperature. And then if I can measure the temperature then I can make a make a correction or compensation for the change in reference temperature, how we will see that now.

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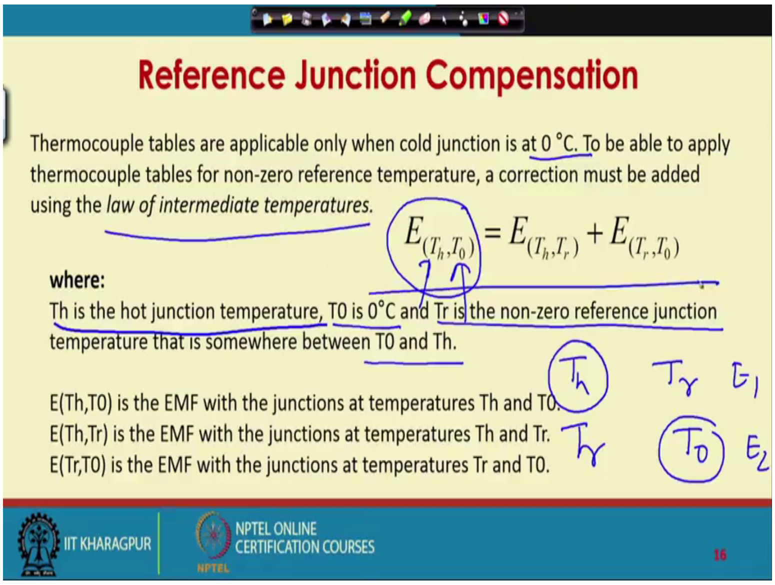

Thermocouple tables are applicable only when cold junction is at 0 degree Celsius. To be able to apply thermocouple tables for non-zero reference temperature, a correction must be added using the law intermediate temperatures. So, what I want the EMF when the thermocouple is kept at temperature T h and temperature 0 degree Celsius. So, T h is the measuring junction temperature, T o or T 0 is the 0 degree Celsius.

Now, if you remember our discussion on laws of thermocouples, when we talked about law of intermediate temperature that if I take a thermocouple which works between temperature T 1 to T 2 and one EMF produces say E 1, and then I take the thermocouple and put and consider the temperatures T 2 and T 3, and then in that case the EMF produced is E 2. Now, if I consider temperatures T 1 and T 3 then the EMF produced will be E 1 plus E 2. So, this is law of intermediate temperature. So, the same law of intermediate temperature can be applied to find out the correction factor when we do not keep the reference junction at 0 degree Celsius.

So, if let us say T h is the junction temperature, T 0 is the 0 degree Celsius, and T r is the non-zero reference temperature. So, T r is the temperature of the reference junction which is not zero, and it is somewhere in between the measuring junction temperature and 0 degree Celsius. So, higher than 0 degree Celsius let us say if we are measuring positive temperatures. So, I want EMF to be between T h and T 0, so I have T thermocouple between T h and T r, and thermocouple EMF between T r and T 0. So, if I now want to know the EMF produced between T h and T 0, I have to sum this E 1 and this E 2, so that is what is being done.

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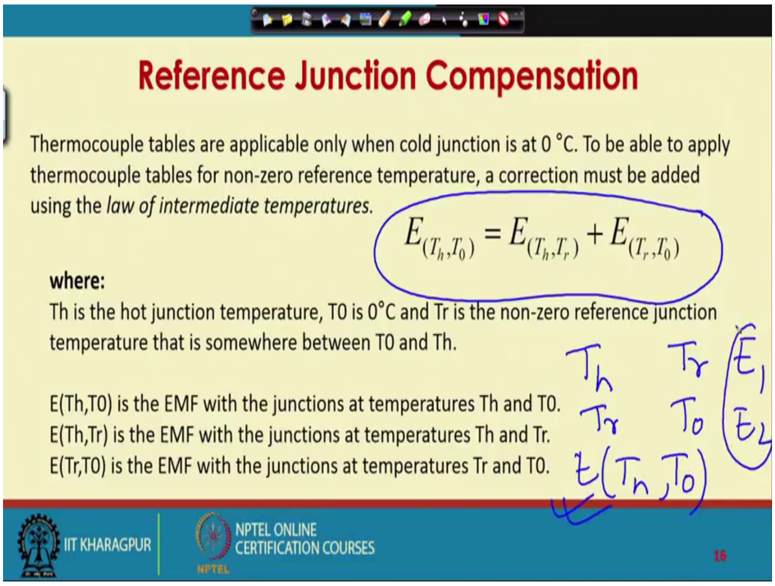

So, when you use a thermocouple for practical application, you have a non-zero reference temperature T r, and let us say measuring junction temperature is T h. So, you have EMF E 1. Now, the thermocouple EMF table will give you EMF for T h, T 0 which is 0 degree Celsius. So, you need to know what is the EMF between thermocouple junctions temperatures at T r and T 0. If this is E 2 you see that this will be E 1 plus E 2 according to law of intermediate temperatures.

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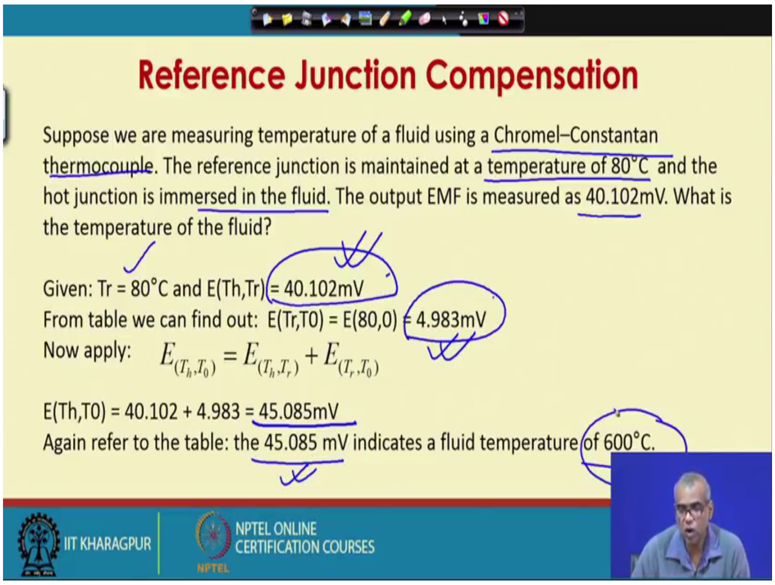

So, let us take a small numerical example, so that this becomes further clarified. Suppose we are measuring temperature of a fluid using a chromel-constantan thermocouple. The reference junction is maintained at a temperature of 80 degree Celsius and the hot junction is immersed in the fluid. The output EMF is measured at 40.102 millivolt. What is the temperature of the fluid? Basically, I am going to measure the temperature of a fluid using chromel-constantan thermocouple, and the reference junction is not at 0 degree Celsius it is kept at 80 degree Celsius. The output EMF is 40.102 millivolt. So, what is the temperature of the fluid.

All I need to do is I need to know what will be the correction factor. So, what will be the correction factor? What is given? Reference temperature is 80 degree Celsius, and the EMF produced between the hot junction temperature and the 80 degree Celsius temperature is 40.102 millivolt that is the output of the thermocouples milli voltmeter. Now, I now need to find out what will be the EMF produced, if I put the thermocouple in between two temperatures which are these reference temperature 80 degree Celsius and 0 degree Celsius. From the table I found out that that is 4.938 millivolt. So, now, I must add this millivolt to this to find out what will be the EMF is the thermocouple is kept in kept between temperatures measuring junction temperature that is fluid temperature and the 0 degree Celsius, so that is going to be 45.085 millivolt, if I add these two numbers.

Now, again you look at the table and you see that 45.085 millivolt corresponds to a temperature which is 600 degree Celsius. If this does not directly fall on any value in the table we have to do the interpolation as we have seen previously. So, the fluids temperature is 600 degree Celsius. So, how do you do the correction? All I do is if the reference temperature is not a 0 degree Celsius, you find out the EMF that will be produced if the thermocouple is kept between temperatures, the reference temperature and the 0 degree Celsius that EMF must be produced to the thermocouple's output and then you can directly look at the table.

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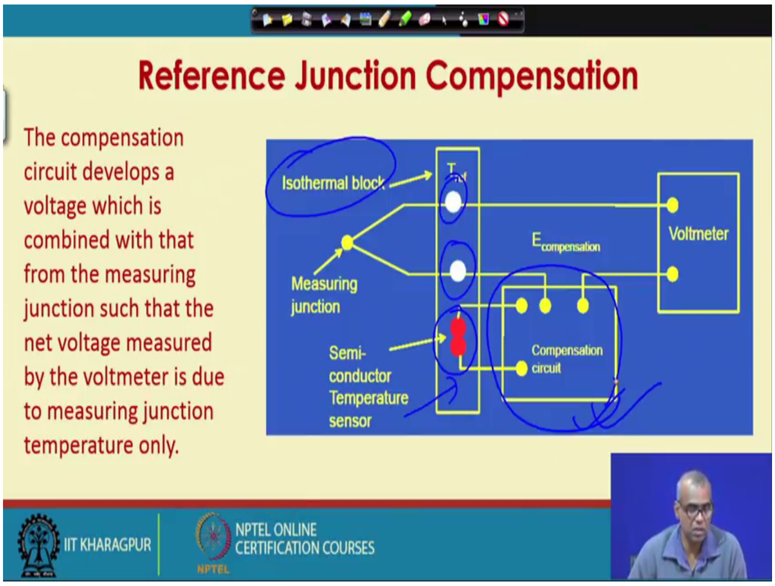

So, whatever we said can also be automated using a microprocessor based device or let us say using a computer. So, the compensation circuit is very simple or it has to do the calculation to find out what is the EMF produced when the two junctions are reference temperature and the 0 degree Celsius. So, what we do is the new junctions that was produced by joining these extension leads are kept at same temperature using an isothermal block. And then I find the temperature of this isothermal block using an independent temperature measuring device, usually a resistance temperature detector or a resistance temperature device RTD is used. Then all these information now can be processed using a computer or a microprocessor based device to find out the correction factor and that can be detected that can be added to the thermocouples milli voltmeter, so that I get the I can compensate for the reference junction. So, the compensation circuit develops a voltage which is combined with that from the measuring junction such that the net voltage measured by the voltmeter is due to measuring junction temperature only.

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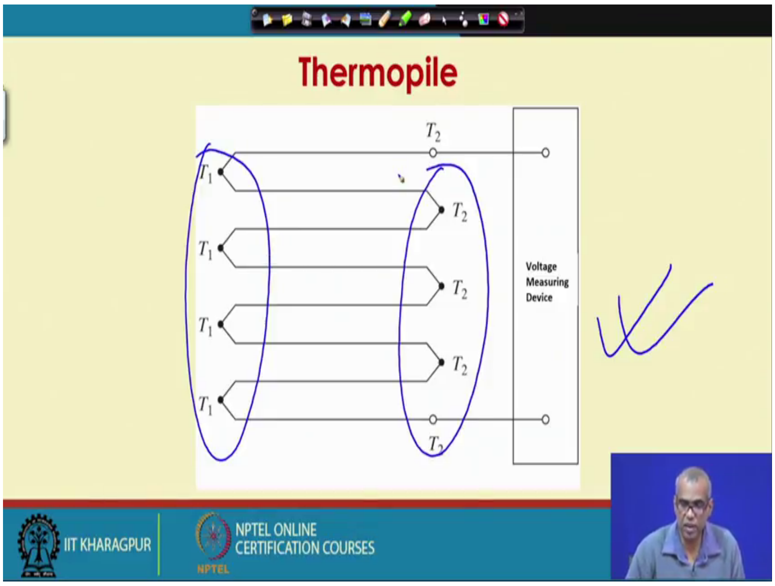

Finally, you can have various thermocouples in series this combination. This is known as thermopiles. So, this is done to increase the output from the thermocouple. So, millivolt the voltage that is produced by single thermocouple may be small. So, now, if I attach if I connect several thermocouples and then we call it a thermopile. So, each thermocouple will be produced the same millivolt and all these millivolts will be added together. So, the overall output from the thermopile will be much more, so that will increase the sensitivity of the thermocouple and it will be easy for the purpose of the measurement. So, this is an example of thermopile where we have see connected various thermocouples, and note that all these junctions are kept at the temperatures T 1 and T 2.

So, we will stop our discussion on thermocouples here.